

Origin and Characterization of Geothermal Waters at Desert Queen, Nevada

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ABSTRACT

The Desert Queen geothermal system, which is in close proximity to two locations where geothermal energy is currently being harnessed, may host an additional reservoir. A $\delta^{18}\text{O}$ vs δD plot indicates that Desert Queen waters likely originate from the Humboldt River, and reflects Humboldt River water that is clearly evaporated. Temperatures of the reservoir at depth are estimated to be between 92-141°C and were calculated using the $\Delta^{18}\text{O}_{(\text{SO}_4\text{-H}_2\text{O})}$ geothermometer. It is unclear whether these temperatures reflect waters from the outflow zone of the Desert Peak geothermal system, or waters from a different reservoir at Desert Queen. Since these temperatures are below 150°C, they indicate borderline exploitable geothermal energy potential. Further investigation by drilling is necessary to determine the true nature of the waters at depth.

Introduction

The Hot Springs Mountains of west-central Nevada are located

roughly halfway between Fernley and Lovelock (Figure 1). There are possibly three geothermal reservoirs in the Hot Springs Mountains. Two known reservoirs are Brady's Hot Springs and the Desert Peak geothermal systems, which lie on the west and south side of the range, respectively. Both currently produce electricity and are known to originate from different sources. Another potential resource is at Desert Queen, a region to the northeast of Brady's Hot Springs and Desert Peak. The Desert Queen aquifer was discovered by temperature gradient drilling in 1974. Speculation by Benoit et al. (1982), structural analysis by Faulds et al. (2003), and temperature probing by Coolbaugh et al. (2007) indicate a favorable environment that could host a third reservoir at this location.

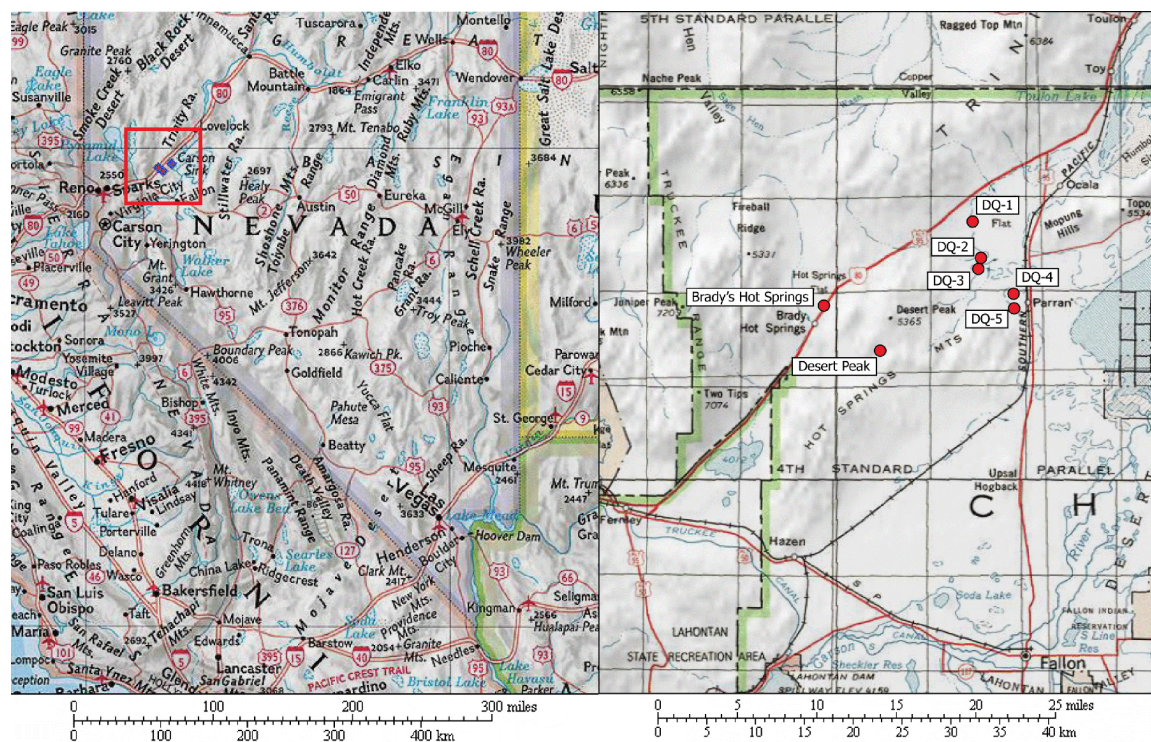


Figure 1. Location where the Desert Queen samples were collected in relation to other geothermal landmarks.

Table 1. Geothermometer equations and temperature ranges. All concentrations are in mg/kg.

Geothermometer	Equation	Temperature
Quartz	$t^{\circ}C = \frac{1309}{5.19 - \log(SiO_2)} - 273.15$	>180°C
Chalcedony	$t^{\circ}C = \frac{1032}{4.69 - \log(SiO_2)} - 273.15$	180-140°C
Amorphous Silica	$t^{\circ}C = \frac{731}{4.52 - \log(SiO_2)} - 273.15$	<140°C
Na-K-Ca	$t^{\circ}C = \frac{1647}{\log\left(\frac{Na}{K}\right) + \beta \left[\log\left(\frac{\sqrt{Ca}}{Na}\right) + 2.06 \right] + 2.47} - 273.15$	>70°C best 180°-300°C $\beta=4/3$ if $T<100^{\circ}C$ $\beta=1/3$ if $T>100^{\circ}C$
$\Delta^{18}O_{(SO_4-H_2O)}$	$t^{\circ}C = H \sqrt{\frac{2.88 \cdot 10^6}{1000 \ln\left(\frac{1000 + \delta^{18}O_{SO_4}}{1000 + \delta^{18}O_{H_2O}}\right)}} - 273$	0-350°C

Table 2. Isotopic signature of Desert Queen waters (data in permil).

Sample	$\delta^{13}C_{VPDB}$	$\delta^{18}O_{VSMOW}$	δD_{VSMOW}	sulfate- $\delta^{34}S_{VCDT}$	sulfate- $\delta^{18}O_{VSMOW}$
DQ-1	-5.0	-8.7	-93	15.9	8.0
DQ-2	-6.5	-9.7	-96	27.2	12.0
DQ-3	-6.1	-9.8	-97	22.3	7.7
DQ-4	-4.6	-9.6	-94	21.3	10.0
DQ-5	-4.3	-9.6	-94	21.6	11.3

Table 3. Concentration of major components in Desert Queen samples (mg/kg).

Sample	SiO ₂	Na	K	Ca	SO ₄	Cl
DQ-1	34.2	6468	286.7	14.2	599	8200
DQ-2	46.2	3855	384.3	50.2	394	4670
DQ-3	72.5	3532	391.2	129	388	4610
DQ-4	48.9	2974	225.4	89.8	476	3470
DQ-5	54.7	2804	189.1	50.6	451	3400

Table 4. Calculated Geothermometer Temperatures (°C).

Sample	Quartz	Chalcedony	Amorphous Silica	Na-K-Ca	$\Delta^{18}O_{(SO_4-H_2O)}$
DQ-1	84	53	-28	211	141
DQ-2	98	68	-17	122	92
DQ-3	119	91	1	228	132
DQ-4	100	70	-14	204	110
DQ-5	106	76	-10	202	98

The purpose of this research was to characterize the waters at Desert Queen by looking at geothermometer temperatures as well as stable oxygen and hydrogen isotopes, and to perform a preliminary assessment of whether further investigation of Desert Queen as a potential geothermal energy resource is warranted.

Methods

Waters from five shallow artesian wells on the Desert Queen playa were collected. The waters were then analyzed in the Nevada Bureau of Mines and Geology (NBMG) analytical laboratory for alkalinity, silica, and cation concentrations. In addition, sulfate- $\delta^{34}S$, sulfate- $\delta^{18}O$, $\delta^{13}C$, $\delta^{18}O$, and δD stable isotope analyses of the waters were conducted at the Nevada Stable Isotope Laboratory. A dropwise titration was also performed by hand in the lab to assess alkalinity, and generally agreed with results from NBMG. The data from these analyses were then compared to available Humboldt River water data (Friedman, 2000) from the Elko, Winnemucca, and Lovelock, NV localities.

Quartz, chalcedony, amorphous silica, Na-K-Ca, and $\Delta^{18}O_{(SO_4-H_2O)}$ geothermometer calculations were performed. The purpose of a geothermometer is to estimate the temperature at depth, given concentrations of dissolved substances at the surface. This method assumes that concentrations at depth are preserved as the waters flow to the surface, and measures the degree to which the substance(s) were in equilibrium at depth. Geothermometer calculations are empirical, but in most cases seem to give a reasonable estimate. Geothermometer equations used in this paper are from Henley et al (1984), and are shown in Table 1.

Results

Geochemical data collected are shown in Tables 2 and 3, and calculated geothermometer temperatures are shown in Table 4. Isotope data for the Desert Queen waters are plotted on Figure 2, along with Humboldt River water data from Friedman (2000). An enthalpy vs. chloride plot is shown in Figure 4. Isotope data for the waters at Desert Queen vary little among samples, with the exception of the sulfate isotopes. Geochemical data for major ions in these waters show very low silica content, about 34-73 ppm. Sodium, potassium, calcium, and sulfate concentrations are all higher than most other geothermal systems globally, as seen in Table 5.

Geothermometry

Calculated temperature values in Table 4 show considerable disagreement, which affects the applicability of these geothermometers to the Desert Queen system.

Since the quartz geothermometer values are below the accepted >180°C temperature range shown in Figure 3, the waters likely would not have been in equilibrium with quartz, rendering these values unreliable, and thus they are not considered useable. Likewise, the chalcedony temperature values are not in the accepted 140-180°C temperature range for this geothermometer, and are also unlikely to be accurate.

The negative temperatures given by the amorphous silica geothermometer are clearly incorrect. Figure 4 shows a graph of

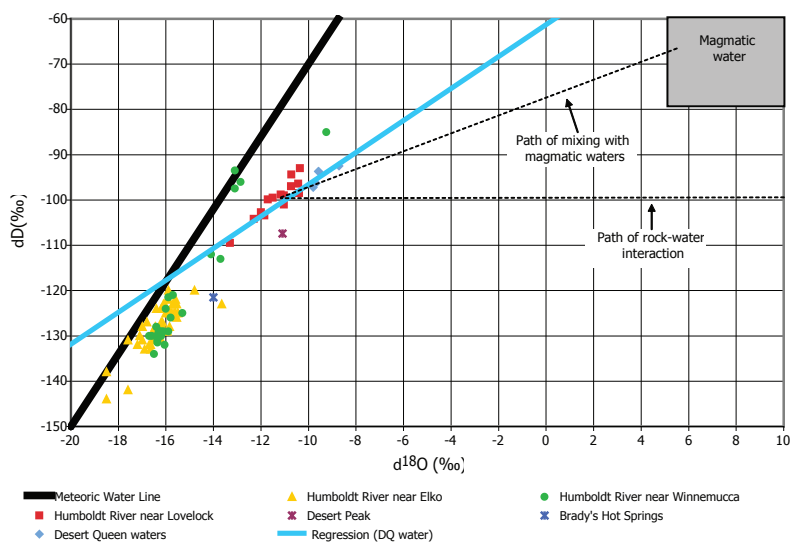


Figure 2. Composition of waters.

Table 5. Concentration of major components in waters discharged from geothermal wells (mg/kg) (Henley et al, 1984).

Geothermal system	SiO ₂	Na ⁺	K ⁺	Ca ²⁺	SO ₄ ⁼	Cl ⁻
Wairakei W24, New Zealand	670	1250	210	12	28	2210
Tauhara TH1, New Zealand	726	1275	223	14	30	2222
Broadlands BR22, New Zealand	848	1035	224	1.43	2	1705
Ngawha N4, New Zealand	464	1025	90	2.9	27	1475
Cerro Prieto CPM19A, Mexico	808	7370	1660	438	18	13800
Mahio-Tongonan 103, Phillipines	1010	7155	2184	255	32	13550
Reykjanes 8, Iceland	631	11150	1720	1705	28	22835
Salton Sea IID1, California	1150	62000	21600	35500	6	191000

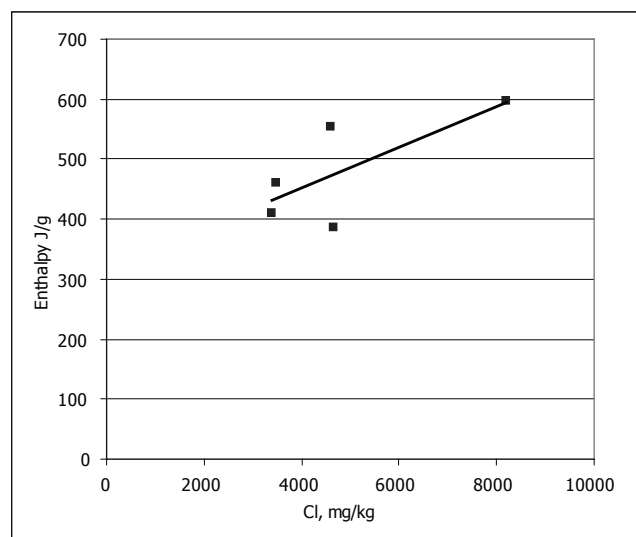


Figure 3. Enthalpy-chloride plot for samples from Desert Queen. Enthalpy data from the sulfate-water isotope thermometer.

the three silica geothermometer equations, and reveals an explanation for these anomalous values. Since the <140°C temperature range corresponds to the amorphous silica geothermometer, the amorphous silica geothermometer equation was considered. The amorphous silica curve intersects the y-axis at 70 ppm silica, indicating a large error associated with the amorphous silica geothermometer equation. Because the amorphous silica geothermometer was calibrated at higher temperatures, a small error in the calibration means a large error when the line is extrapolated to lower temperatures. Since the silica concentrations in the Desert Queen samples were mostly under 70 ppm, the temperature values given by the amorphous silica geothermometer don't make sense because the concentration of the silica is too low for the equation.

The Na-K-Ca geothermometer calculations assume that the water contains dissolved elements in equilibrium with minerals such as feldspars that contain Na, K and Ca. However, this is not necessarily the case for the Desert Queen samples, because there are other sources of these elements, in particular, evaporites in the sedimentary basin fill material. If meteoric waters passed through these evaporites, the concentration of various salts would be much higher than if it were in equilibrium with feldspars and other silicate minerals. Since the samples were collected in close proximity to a salt flat, the concentrations of Na, K, and Ca are likely to be unreliably high. This is also obvious when one compares the Na, K and Ca content of DQ waters to other geothermal systems worldwide (Table 5) where it is clear that DQ waters have elevated sulfate content. Therefore, even though the temperature values from the Na-K-Ca geothermometer appear promising, they are not likely to truly reflect the reservoir temperatures because the water is salty.

The remaining $\Delta^{18}\text{O}_{(\text{SO}_4\text{-H}_2\text{O})}$ geothermometer appears to give more reasonable values than the rest of the geothermometers, but still has potential shortcomings. The oxygen of the water could conceivably be affected by rock-water interaction or by mixing with other subsurface waters. However, both of these mechanisms are considered unlikely, as discussed below. Fast-traveling water would not have time to equilibrate with the rock around it, so rock-water exchange of oxygen-18 is unlikely during its transit from reservoir to the surface. Mixing is also unlikely because the introduced water would have to be quite fresh to shift the oxygen isotope concentration in the direction observed, and it is unlikely that enough fresh water exists in the subsurface to significantly impact the rising geothermal water. Sulfate oxygen-18, however, could easily vary. Sulfate is an anion contained in highly soluble salts like gypsum, and therefore is likely to become dissolved in the rising geothermal waters. The prevalence of salt and evaporite minerals in the Desert Queen area suggests that the sulfate oxygen-18 values may well have been affected. In addition, any apparent temperature change from equilibrium conditions that may result from addition of evaporite sulfate is directly proportional to both the isotopic composition and the amount of the added sulfate. If the added sulfate had the same isotopic composition as the original dissolved sulfate, large amounts could be added with little to no

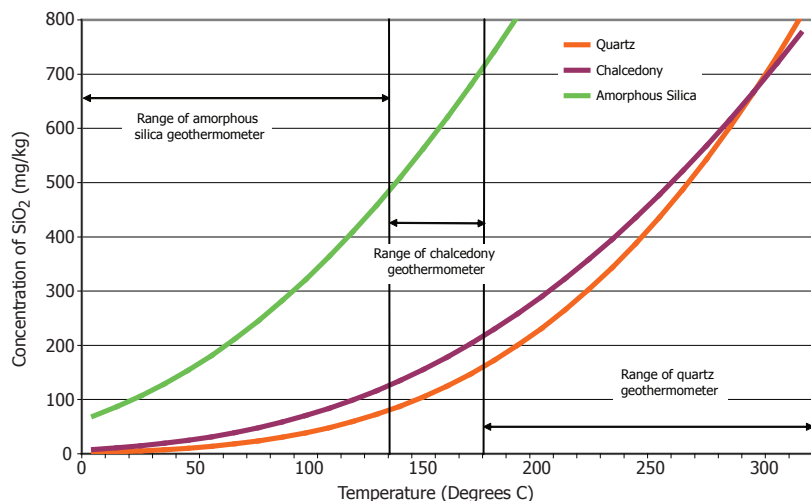


Figure 4. Silica geothermometers.

effect on the isotopic signature, but this would affect the amount of total sulfate in the system. Likewise, if a small amount of added sulfate had a radically different isotopic composition, it would greatly affect the isotopic signature but not do much to the amount of sulfate. The Desert Queen samples clearly have more sulfate than most other geothermal systems (Table 5), indicating a high probability that the oxygen-18 concentrations in the $\Delta^{18}\text{O}_{(\text{SO}_4\text{-H}_2\text{O})}$ geothermometer equation results may be tainted. Because both the isotopic signature and amount is likely to be affected by the addition of sulfates, the possibility that the sulfate oxygen-18 data are not accurately representative of the water is significant.

Using a geothermometer presupposes that the water at depth travels to the surface at a relatively rapid rate, preserving the concentration and isotopic ratios it had at depth. This may not always be the case. The water may have begun to re-equilibrate at the surface, lowering the constituent concentrations, which would be interpreted as a cooler original temperature. Because of this, it is possible that the temperature at depth is higher than the calculated temperatures. None of the geothermometers used in this research is particularly reliable, but the $\Delta^{18}\text{O}_{(\text{SO}_4\text{-H}_2\text{O})}$ temperatures seem the most reasonable.

Origin of Waters

Figure 2 shows where the data lie in relation to the global meteoric water line, which represents the composition of rain water, and is approximated by the equation $\delta\text{D}=8\delta^{18}\text{O}+10$ (Craig, 1963). Data for the Humboldt River at Elko and Winnemucca lie quite close to the meteoric water line, while at Lovelock they show a slight departure from the meteoric water line toward heavier hydrogen and oxygen. This makes sense, as the Humboldt is relatively fresh at Elko, and fed mostly by rainwater. Traveling away from Elko, the results shift increasingly more up and to the right, indicating the effects of evaporation before the Humboldt River dries up just south of Lovelock.

Although it is expected that the $\delta^{18}\text{O}$ values of geothermal waters that originate from local meteoric water may be higher than those of local meteoric water, δD values should remain essentially constant (Henley et al 1984). The departure of the

Desert Queen samples from the meteoric water line can be explained by three processes: mixing with other waters, interacting with rock in the subsurface, or evaporation.

The mixing of two waters would produce a water that plots somewhere along a straight line between the endmembers, since hydrogen and oxygen content of both waters are the same. Mixing of the Desert Queen waters with magmatic water would cause the samples to plot along a diagonal line between the endmember waters, as observed in Figure 2. Because the enthalpy-chloride plot in Figure 3 shows a general linear trend, it is possible that some less evaporated meteoric water is mixing with deeper magmatic water. However, this scenario is considered unlikely as there has been no geologically recent magmatism in the area, and because geothermal systems containing mixed meteoric and magmatic water are rare globally.

Rock-water interaction would produce a water that plots along a horizontal line from its original position. This is because the ratio of oxygen in water is comparable to the ratio of oxygen in rock, so the two influence each other and the overall oxygen isotopic signature is affected, shifting the data directly to the right. Since the content of hydrogen in rock is so much smaller than the content of hydrogen in water, the isotopic signature of hydrogen in water is not changed significantly during most water-rock interaction. In order to change the hydrogen, the water would have to pass through an extremely large amount of rock. The position of the Desert Queen data is not supported by rock-water interaction because the Desert Queen samples show shifted isotopic signatures of both oxygen and hydrogen, and because the water would have to interact with an impossibly large amount of rock to show the observed hydrogen shift. No other geothermal systems are known which show such extensive water-rock interaction.

Neither rock-water interaction nor mixing fully describes the isotopic composition of the Desert Queen samples. Instead, the Desert Queen waters likely originated from the Humboldt River, and reflect Humboldt River water that has simply been highly evaporated. Figure 2 shows that the Desert Queen samples follow the same general trend as the Humboldt River data as evaporation takes place downstream from Winnemucca. We suggest that this indicates that Desert Queen waters likely originate from the Humboldt River, and are simply more evaporated than the Humboldt waters at Lovelock. This hypothesis is consistent with the geography of the area, since the Desert Queen is downstream of the Humboldt at Lovelock.

Energy Implications

Coolbaugh et al (2007) mention a “temperature reversal” that “suggests the presence of a flat-lying thermal aquifer” at the location of the artesian wells sampled for this research. It is possible that this aquifer is derived from the upwelling fluids of the Desert Peak geothermal system, and that all these fluids ultimately come from the Humboldt River. This view is substantiated by the fact that the Desert Peak water sample plots very near those for the Humboldt River at Lovelock, and that the Desert Queen results are

shifted up and to the right from the Desert Peak sample, suggesting additional evaporation beyond what has occurred at Desert Peak. In addition, the enthalpy vs chloride graph using the calculated $\Delta^{18}\text{O}_{(\text{SO}_4\text{-H}_2\text{O})}$ geothermometer temperature shows a somewhat linear trend, indicating that some local mixing is also possible.

This conclusion is not especially helpful in determining whether or not Desert Queen contains an exploitable resource, but does yield insight into the origin of the waters. Drilling would give more accurate temperatures and reveal the true nature of the waters at depth.

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